Left ventricular mass in coronary artery disease without hypertension
Haemodynamic and angiocardiographic study

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Left heart catheterization, quantitative angiocardiography, and selective coronary angiography were undertaken in 64 patients with angina pectoris. The patients were subdivided into four groups according to severity of coronary arteriosclerosis. The mass of the left ventricle was significantly increased in patients with coronary artery disease as compared to those with normal coronary arteriograms.

No correlation could be found between left ventricular mass and left ventricular stroke work. Significant correlations were observed with end-diastolic tension and pressure, and a lesser correlation with end-diastolic volume, in patients with advanced coronary arteriosclerosis. Higher end-diastolic wall tension represents compensation by the Frank-Starling mechanism to maintain adequate stroke work. Increased left ventricular mass seems to be the result of and to compensate for, a higher wall tension.

Post-mortem investigations in certain cases of coronary arteriosclerosis or myocardial infarction (without hypertension) have revealed hypertrophy of the left ventricle (Busch, 1953; Ellis *et al.*, 1962; McCain, Kline, and Gilson, 1950; Murata *et al.*, 1972; Zaino and Tabor, 1963). While such hypertrophy is believed to be a compensatory process, its actual pathogenetic mechanism has not yet been elucidated (Badeer, 1971, 1972). Necropsy alone is not sufficient for elucidation and must, therefore, be complemented by additional *in vivo* haemodynamic and metabolic studies.

The advent of coronary angiography and left ventriculography has permitted *in vivo* assessment of the coronary vessels and of left ventricular dimensions and mass (Rackley *et al.*, 1970).

This study presents a comparison between results obtained by haemodynamic and angiocardiographic measurement and those recorded by coronary angiography from patients with chronic ischaemic heart disease.

Patients and methods

The findings referred to in this paper were obtained from 64 patients (61 male, 3 female), aged between 32 and 62, who had undergone diagnostic left heart catheterization,

including angiocardiography, and selective coronary arteriography for investigation of chest pain (Table 1). (Patients with arrhythmia, blood pressure in excess of 140 mmHg systolic, primary cardiomyopathy, aortic valve disease, and aneurysm of the left ventricle were excluded from this study.)

The patients were subdivided into four groups, with reference to morphologic results obtained by coronary angiography:

Group 0: Normal coronary arteriogram.

Group I: Plaques or stenosis.

Group II: Stenosis of a major vessel with evidence of haemodynamic insufficiency (retrograde filling of the post-stenotic part of the vessel by collateral circulation, considerably delayed filling of the post-stenotic part of the left anterior descending or circumflex branch compared with the parallel vessel, or asynchrony in the left ventriculogram, as described by Herman *et al.* (1967).

Group III: Occlusion of a major vessel (main right coronary artery, left anterior descending branch, left circumflex branch).

Catheterization was performed after moderate sedation and under local anaesthesia. After retrograde catheterization from the femoral artery, 40 to 60 ml 'Visotrast 370'[1] were injected continuously or intermittently into

[1] VEB Fahlberg List, Magdeburg.

TABLE I   *Synopsis of data from 64 patients with angina pectoris*

Group	No.	Sex M	F	Age (yr)	LV mass (g/m²)	LV end-diastolic vol. (ml/m²)	LV end-diastolic pressure (mmHg)	LV end-diastolic tension (dyne/cm·10³)	Tension mass index (dyne/cm/g·10⁻²)	LV stroke work index (kpm/min/m²)	Work mass index (g m/min/g)
O	15	13	2	41·0±9·0 (25–61)	93±16·5 (70–134)	80±13·4 (56–97)	7·5±3·2 (6–9)	24±4·6 (16–31)	24±6·2 (13–38)	5·7±1·8 (3·1–8·9)	56±18·4 (27–80)
I	13	13	—	49·2±7·3 (42–61)	107±20·6 (77–140)	94±15·7 (75–119)	7·4±1·6 (5–9)	25±5·6 (16–31)	23±5·6 (14–33)	5·5±1·6 (3·1–7·7)	52±13·6 (34–72)
II	14	14	—	44·9±9·1 (32–62)	127±30·3 (86–204)	88±27·0 (40–130)	9·9±3·2 (5–14)	31±11·9 (14–45)	24±7·5 (15–36)	5·1±1·8 (2·4–7·8)	44±19·0 (17–88)
III	22	21	1	49·1±6·7 (38–62)	125±37·3 (60–214)	113±43·1 (44–244)	12·7±7·7 (5–38)	43±32·5 (15–165)	34±17·1 (16–77)	3·7±1·6 (1·0–7·2)	34±18·9 (5–76)

the left ventricle, using an automatic high-pressure injector. Cine ventriculograms were made at 50 frames/sec in anteroposterior and lateral projections, using a 'cine pulse unit'[1] and an Arriflex 35-mm camera.

Left ventricular pressure was recorded by means of a P23 Statham pressure transducer just before injection of contrast medium, and all pressures were related to a zero level 5 cm below the sternal angle.

Ventriculography was followed by selective coronary arteriography by the technique of Judkins (1968).

The cine film was viewed on a projector and a cardiac cycle selected for volume and mass determination. Calculations were performed at end-diastolic (Q wave of

[1] Philips, Einthoven.

simultaneously recorded electrocardiogram) and end-systolic (end of T wave) phases. The outline of the ventricle was traced from these projections. Wall thickness of the left ventricle was measured from end-diastolic films in the anteroposterior projection approximately half-way between the apex and the aortic valve (Fig. 1).

Evaluation of recordings that showed extrasystoles during contrast medium injection was restricted to those frames that had been preceded by at least one normal ventricular contraction.

The following haemodynamic and angiocardiographic parameters were evaluated.
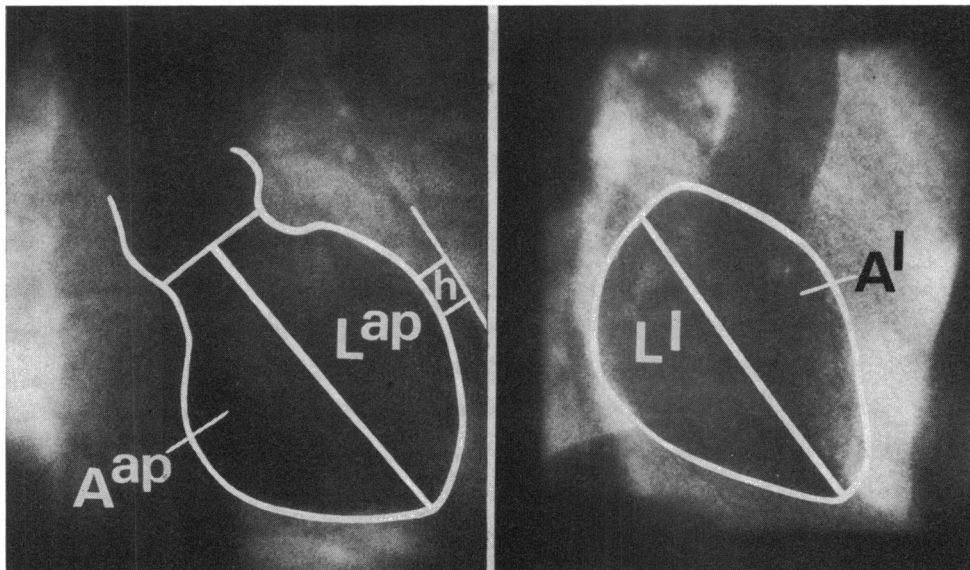
1) End-diastolic volume of left ventricle (LVEDV).

FIG. I   *End-diastolic biplane angiocardiogram of left ventricle in anteroposterior* (left) *and lateral* (right) *projections* (L = long axis, A = projection area, h = wall thickness).

2) End-systolic volume of left ventricle (LVESV); both LVEDV and LVESV were determined by the 'area length method', described by Dodge and co-workers (1960).

3) Left ventricular stroke volume (LVSV). LVSV = LVEDV − LVESV.

4) Left ventricular end-diastolic pressure (LVEDP), measured at beginning of isometric contraction.

5) Left ventricular stroke work index (LVSWI). LVSWI = 0·0136 · (LVMP − LVEDP) · LVSV · heart rate (where LVMP is the mean systolic pressure in the left ventricle, measured by planimetry).

6) End-diastolic (circumferential) wall tension of the left ventricle (LVEDT), according to thin-walled ellipsoidal model of Sandler and Dodge (1963).

7) Muscle mass of left ventricle (LVM), estimated by the method of Rackley and co-workers (1964).

8) Work-mass index $= \dfrac{LVSWI}{LVM}$.

9) Tension-mass index $= \dfrac{LVEDT}{LVM}$.

10) Values for volumes and mass of the left ventricle are normalized for body surface area.

Further methodological details have been reported in our earlier publications (Pech and Porstmann, 1968a, b, c; Pech, 1973; Pech *et al.*, 1973).

Correction for *x*-ray magnification and spherical aberration of the electromagnetic lens system was made by the technique of Kasser and Kennedy (1969). After investigation, a brass plate with 1 cm² cross perforations was filmed in the position of the left ventricle and at an equal distance from the image intensifiers. The correction factor was calculated by superimposing the ventricular tracing and the 1 cm² point pattern of perforations.

The actual area (A_a) of the left ventricle was measured by counting the number of 1 cm squares which enclosed the opacified ventricle, and from its ratio to the planimetered area (A_p) the linear correction factor (K) was determined in the following way:

$$K = \sqrt{\frac{A_a}{A_p}}.$$

Each axis of the ventriculogram was corrected by the above factor. Significance was verified by means of the unpaired t-test.

Results

All values recorded from the 64 patients with and without coronary arteriosclerosis are given in Table 1.

In Group I, the left ventricular mass was significantly increased (t = 2·31; P < 0·05), and highly significant increases were recorded from Groups II and III (t = 3·96 and t = 3·33 respectively, P < 0·001), as compared with the cases without coronary artery disease (Group O) (Fig. 2).

In no group was there a correlation between stroke work index and the mass of the left ventricle, though LVSWI and the index LVSWI/LVM were significantly lower in Group III (t = 3·40 and t = 3·42 respectively, P < 0·001) than in the control group (Fig. 3).

In patients with coronary arteriosclerosis end-diastolic tension, pressure, and volume tended to be high, but in all groups there were some patients whose haemodynamic parameters remained normal under resting conditions (Table 1). There were
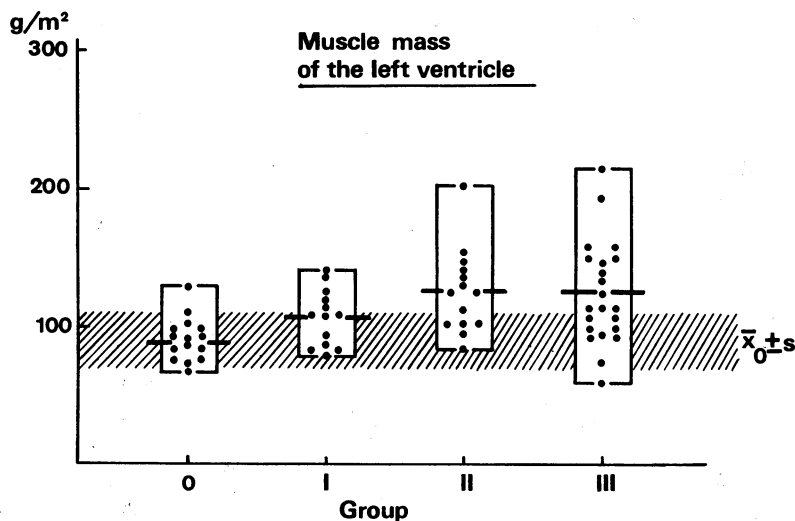

FIG. 2 *Mass of left ventricle in four groups of patients with (I, II, III) and without (O) coronary artery disease (hatched area represents mean value of control group ± standard deviation).*
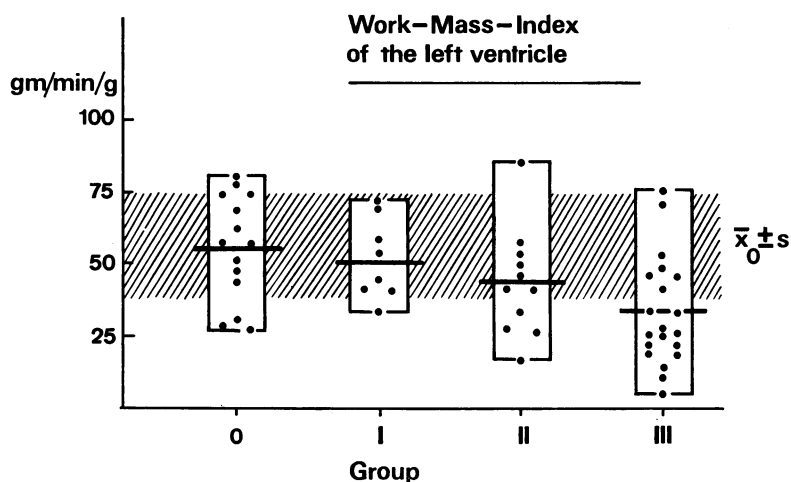
FIG. 3 *Work-mass index of left ventricle; Group III differs significantly from control group*
$(t = 3\cdot42; P < 0\cdot01)$.

significant correlations between the mass of the left ventricle and end-diastolic tension and pressure in Groups II and III, whereas a less significant correlation was found for the end-diastolic volume (Table 2).

There were no significant differences between the groups with regard to the tension-mass index. Values higher than the average of other groups were recorded only from 5 patients with coronary artery occlusion (Fig. 4) $(t = 0\cdot441, t = 0\cdot026, \text{and } t = 2\cdot02, P > 0\cdot05$, for Groups I, II, and III, respectively).

Discussion

At the present time, quantitative angiocardiography is generally accepted as the best method for approximate determination of left ventricular muscle mass *in vivo*. Studies by Kennedy *et al.* (1967), comparing angiographic with necropsy measurements of left ventricular mass, seem to suggest that fair

agreement can be expected as long as the wall thickness, determined at the lateral outline of the heart, is representative of the entire circumference. For this reason, no case with deformation of the ventricular cavity by aneurysm has been included in the scope of this study.

No correlation was found to exist between the estimated mass of the left ventricle and 'external' work (LVSWI). This was expected, since all the patients were normotensive, and there was no significant difference in cardiac output between the groups. Significant reduction in LVSWI in Group III results from a smaller difference between mean and end-diastolic left ventricular pressures.

Some patients with severe coronary arteriosclerosis showed an increase in end-diastolic wall tension; this should be interpreted as compensation by the Frank-Starling mechanism, whereby an adequate cardiac output is maintained by higher wall tension. Increased wall tension is accompanied

TABLE 2 *Correlations between left ventricular muscle mass (g/m^2) and haemodynamic parameters in patients with coronary heart disease*

Haemodynamic parameter	Group I	II	III
LV stroke work index (kpm/min/m²)	r = 0·330* N = 8	r = −0·129* N = 11	r = −0·349* N = 20
LV end-diastolic tension (dyne/cm)	r = 0·309* N = 10	r = 0·652† N = 13	r = 0·619‡ N = 20
LV end-diastolic pressure (mmHg)	r = 0·230* N = 10	r = 0·646† N = 13	r = 0·664‡ N = 20
LV end-diastolic volume (ml/m²)	r = 0·325* N = 13	r = −0·049* N = 14	r = 0·551‡ N = 22

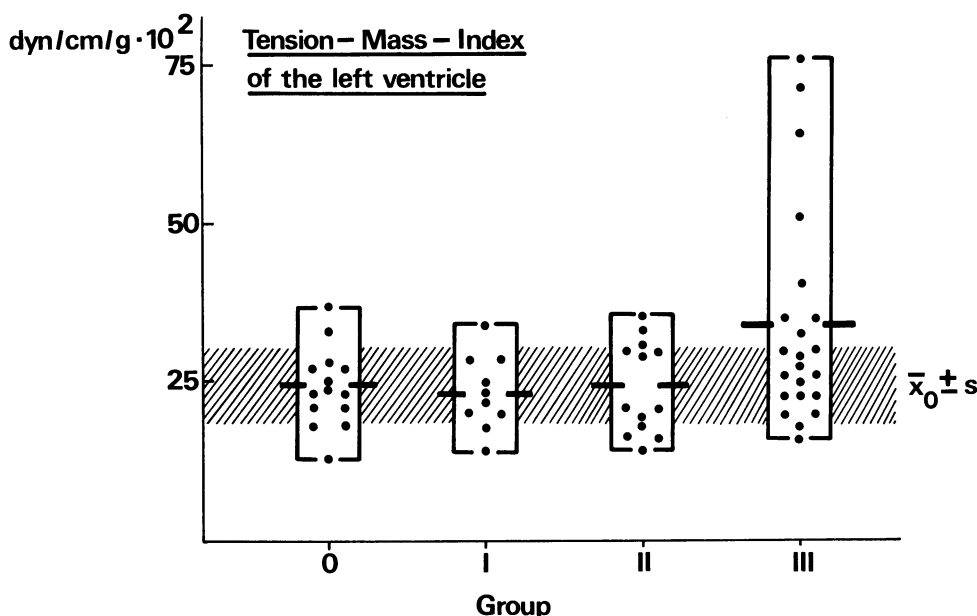* = not significant   † = P < 0·05   ‡ = P < 0·01.

FIG. 4 *Tension-mass index of left ventricle; no significant differences between groups (I, II, III) with coronary artery disease and control group (O).*

by increasing mass of the left ventricle; however, performance related to mass tends to decline in cases with advanced coronary arteriosclerosis. We can only speculate as to the genesis of the increase in left ventricular weight. Probably this can be attributed to two causes: proliferation of connective tissue due to repair of hypoxic necroses and vicarious hypertrophy of the remaining myocardium (Badeer, 1972; Meerson, 1969). At present there is no method for *in vivo* differentiation of the connective tissue component from cardiac muscle.

Weight increase accompanied by increased diastolic wall tension, as calculated, seems to suggest an alteration of the contraction mechanism, a phenomenon assumed by Badeer (1971, 1972) to occur with hypertrophy of the heart in the course of chronic ischaemia.

Thus, increase in the weight of the ventricle might be a process which counteracts the high wall tension which usually results from left ventricular dysfunction caused by coronary arteriosclerosis. Such an assumption appears to be supported by our own cases which failed to show any significant change in the tension-mass index.

Necropsy investigations (Adler and Sandritter, 1971; Eisenstein and Wied, 1970) have shown that rising myocardial weight is accompanied by activation of the synthesis of protein and new formation of contractile structures. In acute experiments non-infarcted areas of myocardium have been shown to exhibit the same changes after induced ischaemia (Gudbjarnason, Braasch, and Bing, 1968). Further research, including metabolic studies, will be required to establish whether or not the same process occurs in hypertrophy of the left ventricle caused by chronic ischaemia in man.

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